Radio Frequency Interference Working Group

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CMB-S4

RFI working group

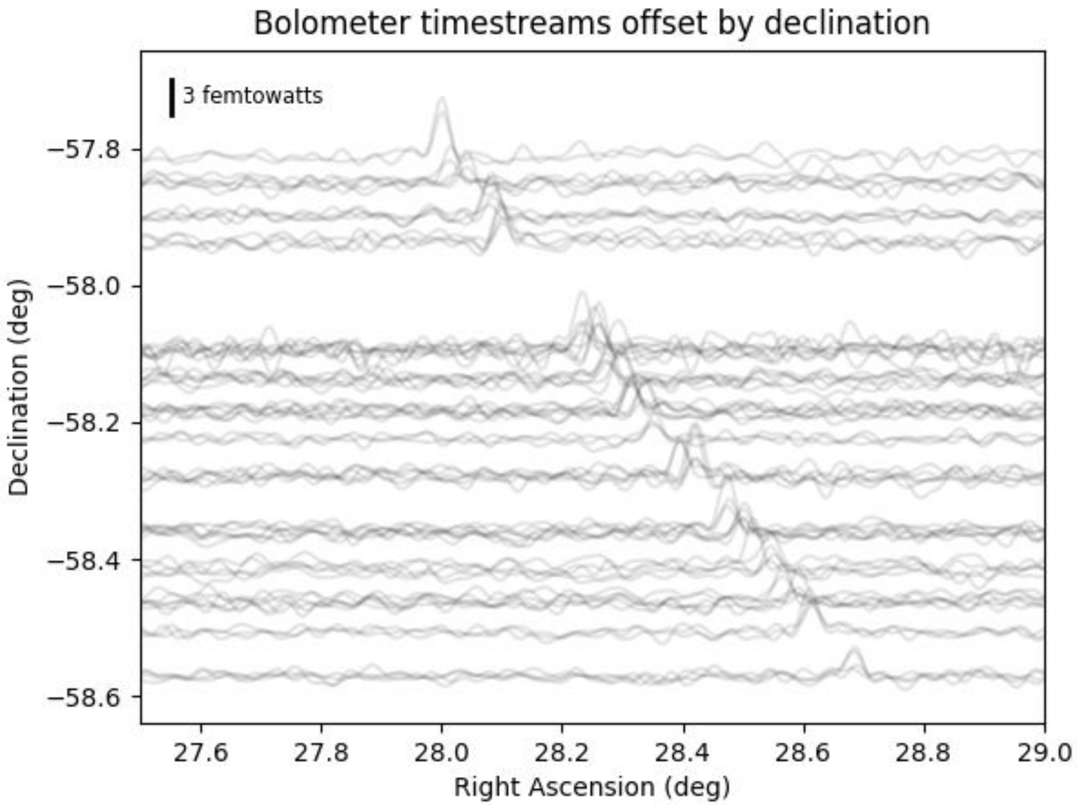
Charge:

- Study the RFI environment relevant to CMB-S4 now, and that expected over the life of the project, for South Pole and Chilean sites.
- Consider ground-based and satellite transmitters, and regulatory constraints.
- Assess the potential impact on CMB-S4 observations.
- Produce a report summarizing findings and recommendations

Defining RFI

- In-band
  - Ka-band satellite transmissions
  - Harmonics of microwave or millimeter-wave transmitters (Example 1)
- Out-of-band
  - RFI from lower-frequency emissions: UHF radios, microwave comms, WiFi (Examples 2, 3)
- Directly coupled
  - Absorbed in detectors, producing bolometric response
- Indirectly coupled
  - RFI pickup in readout system

Example 1



Detection of GRACE-FO 2 in SPT-3G data

SNR ~ 5 in single bolometer timestreams at 150 GHz

Crossing time ~1.5s

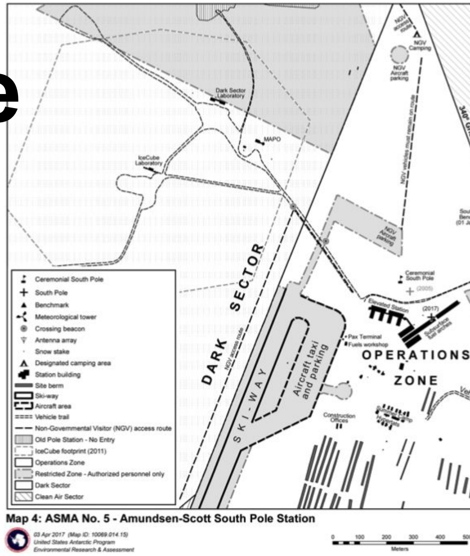
Consistent with 6th order harmonics from G-FO2 K-Band antenna

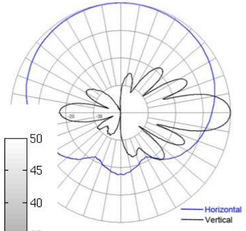
Back-of-the-envelope power works out, but large uncertainties

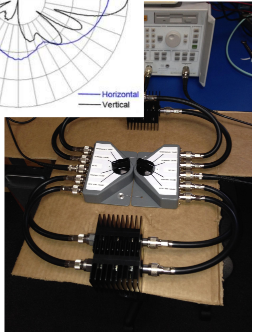
For details, see this presentation by Sam Guns

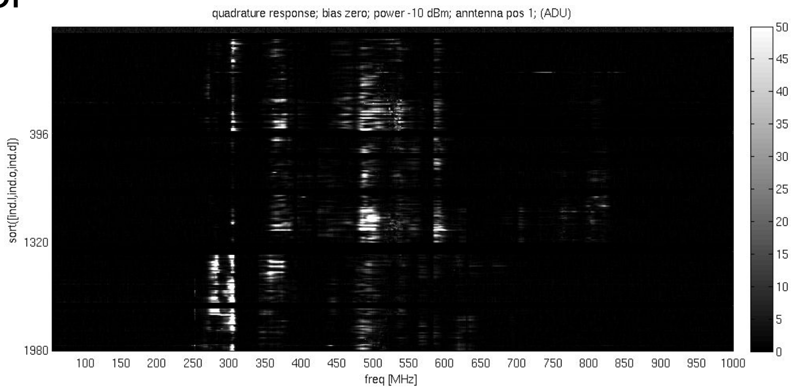
Example 2(a) - RFI at South Pole

- Spectrum management is led by NSF/USAP, and coordinated through Pole EMI Working Group
  - “Dark Sector” EMI [protected by Antarctic Treaty]() (update due 2022)
- CMB experiments have led [site spectrum monitoring](), [online]().
- In 2015, BICEP3 suffered excess AZ-dependent noise
- 6 months of effort to localize source in space/freq found:
  - local 450 MHz handheld LMR system trunk transmitter on station roof; power had been increased to penetrate new metal siding
  - AND BICEP3’s 68cm optics tube lowered cutoff frequency 500 → 259 MHz
- Solution (w/ NSF blessing): LMR attenuator + sector antenna, reduced 30-50 dB @ Dark Sector





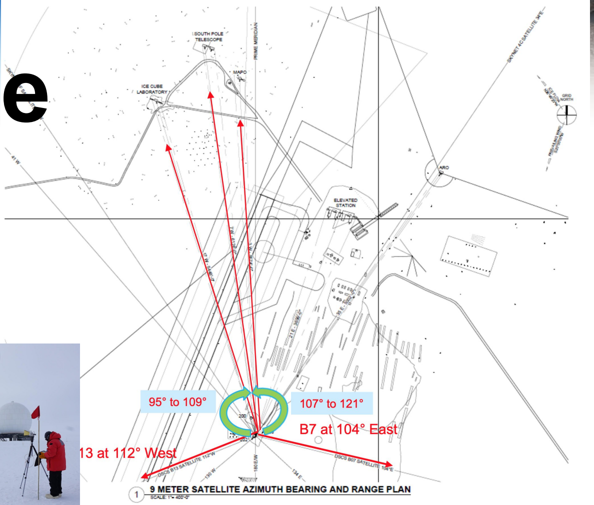


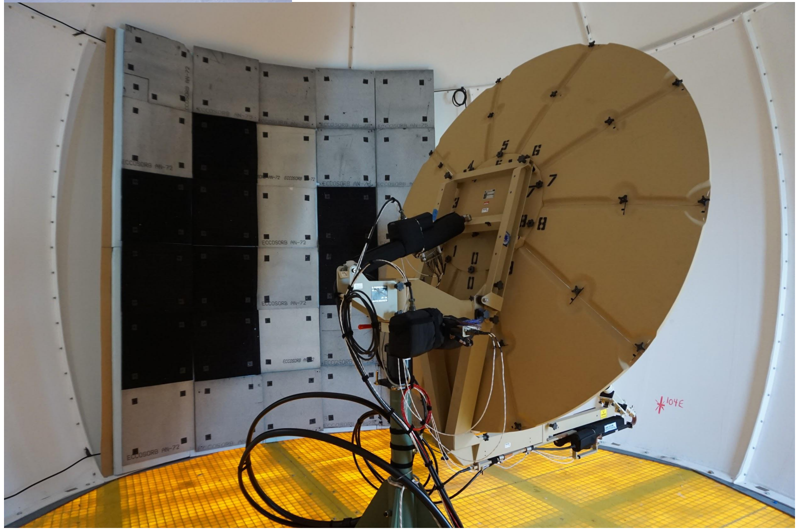


Example 2(b) - Satcom at Pole

- Satellite uplink terminals at Pole are in radomes ~1700m from Dark Sector, providing bulk data (~500 GB/day) and internet
- They connect to a variety of satellites 2-15 GHz, each at roughly fixed AZ
- Sometimes we see their sidelobes!
- We’ve worked with NSF and the contractor to mitigate stray Satcom RFI toward the Dark Sector, by restricting AZ lines of sight and erecting RF barriers
- CMB telescope pickup experience informs our current working requirement:
  - Integrated 2-15 GHz Satcom must be

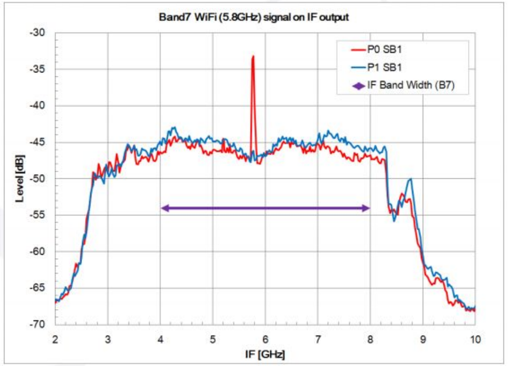
$$< 10\ \mathrm{nW/m^2} \text{ at Dark Sector}$$





Example 3 - RFI at Chajnantor Plateau

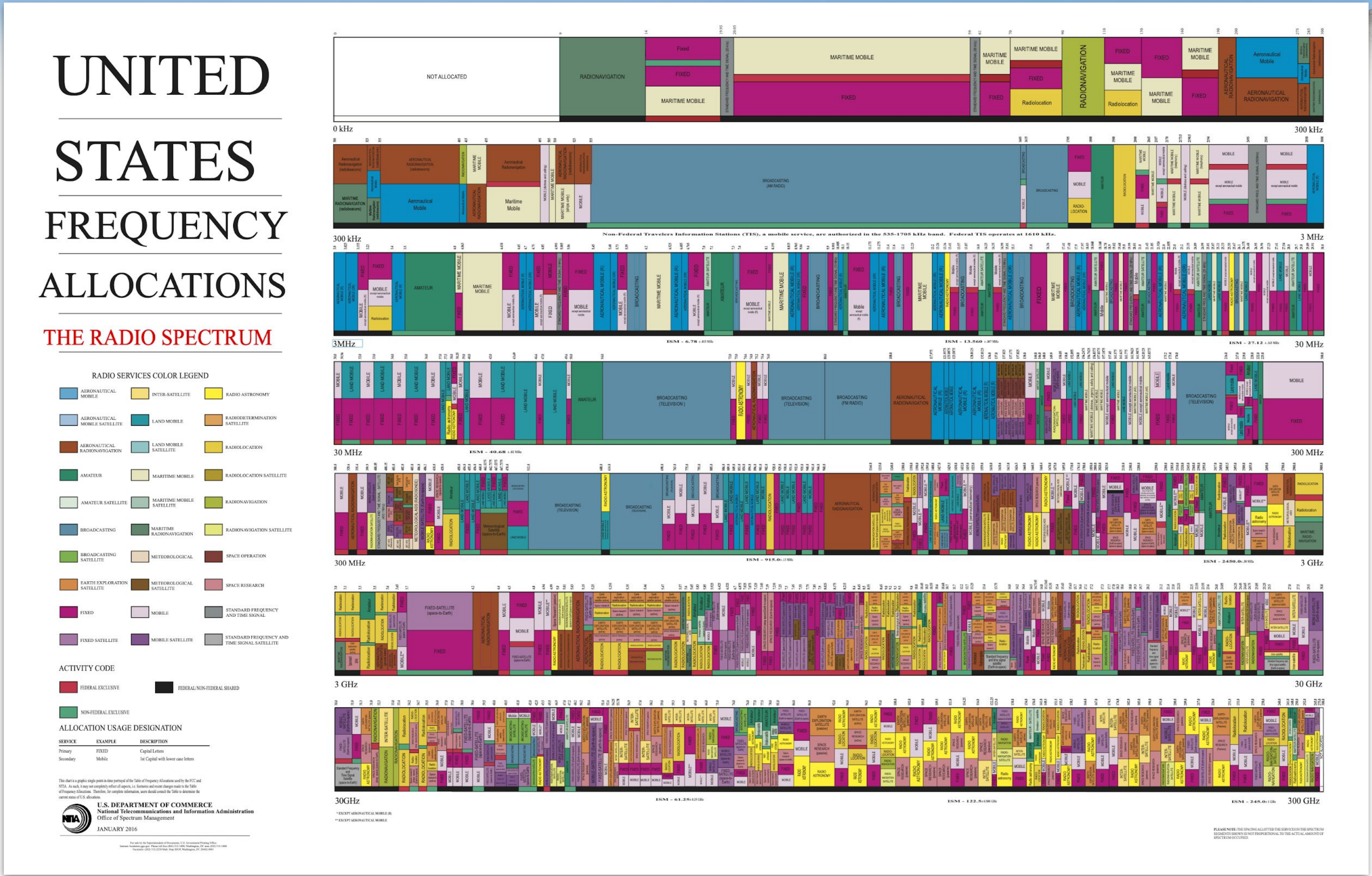
- Spectrum management is led by ALMA, and coordinated through Chajnantor Working Group
- Sources of direct coupling to ALMA band are prohibited
  - Including 5 GHz WiFi
- CMB experiments are all close together on Cerro Toco
- CLASS's 40 GHz receiver clearly detected a signal when pointed at POLARBEAR's location in azimuth
  - Resolved by reducing WiFi power
  - No signal outside of control container
- Similar issue happened with interference from construction crew WiFi at SO site

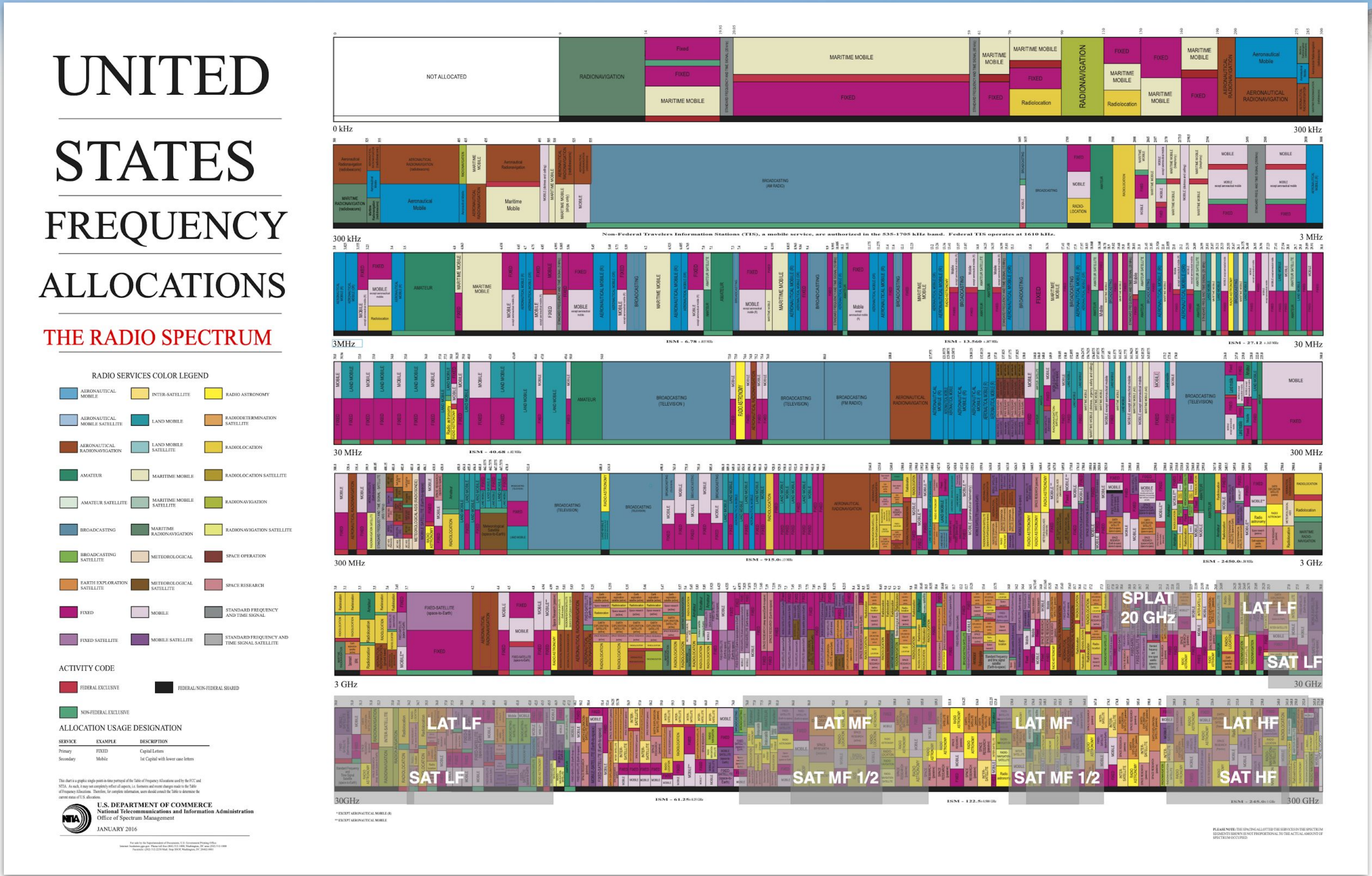


ALMA Lab Measurement of 5.8 GHz WiFi Interference (Nick Whydby)

The regulatory environment

- Radio astronomy protections
  - The ITU Radio Regulations (an international treaty) include protected bands, generally covering galactic line frequencies
  - Quiet zones, mainly focused on ground-based transmitters, not (yet) for satellites
  - Interference thresholds and methodology for single-dish telescopes and interferometers are described in ITU Recommendation RA.769.
- CMB experiments necessarily use unprotected spectrum
  - Currently, de facto protection is through remote location, local coordination.
  - Large satellite constellations threaten this protection model.
  - Both deep maps and transient observations have different sensitivity to RFI than the cases considered in RA.769 - we need to develop appropriate methodology for establishing interference thresholds.


UNITED STATES FREQUENCY ALLOCATIONS
THE RADIO SPECTRUM
RADIO SERVICES COLOR LEGEND
AERONAUTICAL MOBILE
INTER-SATELLITE
RADIO ASTRONOMY
AERONAUTICAL MOBILE SATELLITE
LAND MOBILE
RADIODETERMINATION SATELLITE
AERONAUTICAL RADIONAVIGATION
LAND MOBILE SATELLITE
RADIOLOCATION
AMATEUR
MARITIME MOBILE
RADIOLOCATION SATELLITE
AMATEUR SATELLITE
MARITIME MOBILE SATELLITE
RADIONAVIGATION
BROADCASTING
MARITIME RADIONAVIGATION
RADIONAVIGATION SATELLITE
BROADCASTING SATELLITE
METEOROLOGICAL
SPACE OPERATION
EARTH EXPLORATION SATELLITE
METEOROLOGICAL SATELLITE
SPACE RESEARCH
FIXED
MOBILE
STANDARD FREQUENCY AND TIME SIGNAL
FIXED SATELLITE
MOBILE SATELLITE
STANDARD FREQUENCY AND TIME SIGNAL SATELLITE
ACTIVITY CODE
FEDERAL EXCLUSIVE
FEDERAL/NON-FEDERAL SHARED
NON-FEDERAL EXCLUSIVE
ALLOCATION USAGE DESIGNATION
U.S. DEPARTMENT OF COMMERCE
National Telecommunications and Information Administration
Office of Spectrum Management
JANUARY 2016
0 kHz
300 kHz
3 MHz
30 MHz
300 MHz
3 GHz
30 GHz
300 GHz
NOT ALLOCATED
RADIONAVIGATION
MARITIME MOBILE
FIXED
BROADCASTING (AM RADIO)
BROADCASTING (TELEVISION)
BROADCASTING (FM RADIO)
AMATEUR
AERONAUTICAL RADIONAVIGATION
FIXED-SATELLITE (space-to-Earth)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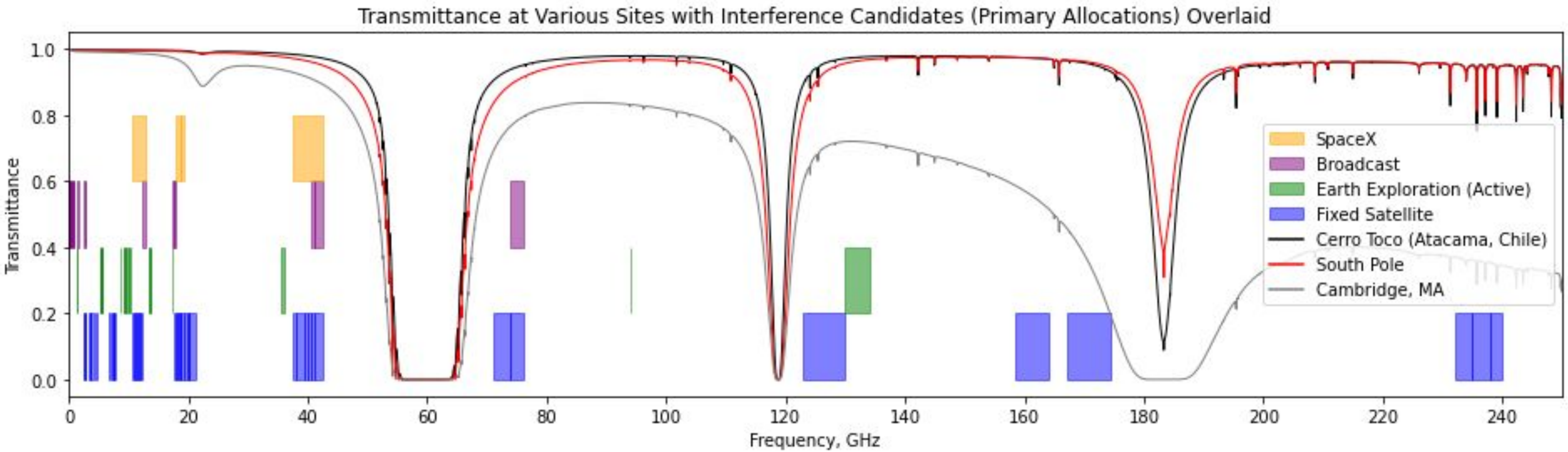
0 kHz
300 kHz
3 MHz
30 MHz
300 MHz
3 GHz
30 GHz
300 GHz
SPLAT 20 GHz
LAT LF
SAT LF
LAT MF
SAT MF 1/2
LAT HF
SAT HF

Direct emissions in CMB-S4 bands



Next - look at an RFI estimate for SpaceX Starlink, from Ian Birdwell's poster yesterday.

Modeling example - SpaceX Starlink

- Starlink is presently the most actively growing satellite constellation, with over 1,000 satellites presently in orbit, and an ongoing beta test for Internet service
- Starlink is cited as having an effective isotropic radiated power (EIRP) of -11.07 dBW/4KHz in the *Ka* band (specifically from 37.5-40.0 GHz)
- To develop a model for RFI, we perform the following steps:
  - First, determine transmittance values at different zenith angles using *am* (Atmospheric Model)
  - Then, for each zenith angle, use the EIRP as an approximation to determine the strength of signal at Cerro Toco based on satellite distance
  - Lastly, combine these figures and use the effective area of a receiver to determine the coupled power affecting the detector
- Starlink satellites use a phased array, which may prompt a significant sidelobe response.

Modeling example - SpaceX Starlink cont.

- Assuming 0 dBi (isotropic) sidelobe model
  - Expect large (~30 dB) improvement from baffling and shielding, but sidelobes remain.
- Compare with SAT LF PBDR figures:
  - Detector optical loading of 1.1 pW
  - Detector saturation load of 2.8 pW
  - NEP of 20 aW / √Hz
    - SNR of approximately 37,000 for a 1 s RFI event

Altitude of Satellite, Degrees	Coupled Power, pW
0	0.743
13	0.705
26	0.598
39	0.446
52	0.227
65	0.126

CMB-S4

Next steps

- Quantitatively assess RFI threats and scientific impacts
- Study mitigation strategies (e.g. coordination, thresholding, site spectrum monitoring, use of satellite ephemeris data)
- Produce draft RFI report and recommendations for CMB-S4
- Monitor and contribute to related developments at NSF and US ITU working groups
- Contribute to evolving management plans for South Pole and Chile sites
- Monitor developing RFI threats in the commercial and public sphere

RFI working group Confluence page with link to Google drive:

https://cmb-s4.atlassian.net/wiki/spaces/XPI/pages/275513374/Radio+Frequency+Interference+Working+Group